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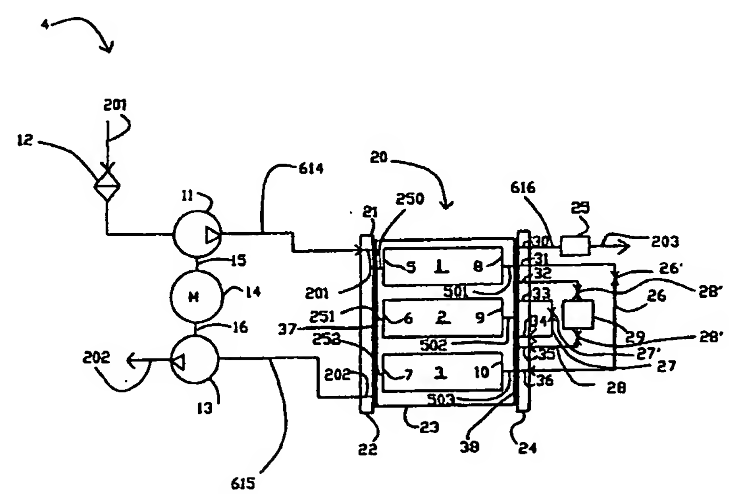

(57) Abstract: Gas separation by pressure swing adsorption (PSA) and vacuum pressure swing adsorption (VPSA), to obtain a purified product gas of the less strongly adsorbed fraction of the feed gas mixture, is performed with an apparatus having a plurality of adsorbers. The adsorbers cooperate with first and second valve means in a rotary PSA module, with the PSA cycle characterized by multiple intermediate pressure levels between the higher and lower pressures of the PSA cycle. Gas flows enter or exit the PSA module at the intermediate pressure levels as well as the higher and lower pressure levels, under substantially steady conditions of flow and pressure. The PSA module comprises a rotor containing laminated sheet adsorbers and rotating within a stator, with ported valve faces between the rotor and stator to control the timing of the flows entering or exiting the adsorbers in the rotor. Feed gas is compressed prior to entry to the first valve means. Exhaust is passed either directly or through a vacuum pump to the atmosphere.

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LIFE SUPPORT OXYGEN CONCENTRATOR

FIELD OF THE INVENTION

The invention relates to gas separations conducted by pressure swing adsorption (PSA), and in particularly to air separation to generate concentrated oxygen or to air purification to remove carbon dioxide or vapor contaminants. In particular, the present invention relates to a rotary valve gas separation system having a plurality of rotating adsorbers disposed therein for implementing a pressure swing adsorption process for separating out the gas fractions.

Three applications of the present invention are:

- Home use medical oxygen concentrators.
- Portable oxygen concentrators.
- Ultra low power oxygen concentrators, e.g. for third world medical clinics.
- Manually operated oxygen concentrator or air purifier for survival life support.

BACKGROUND OF THE INVENTION

Gas separation by pressure swing adsorption is achieved by coordinated pressure cycling and flow reversals over an adsorber that preferentially adsorbs a more readily adsorbed component relative to a less readily adsorbed component of the mixture. The total pressure is elevated during intervals of flow in a first direction through the adsorber from a first end to a second end of the adsorber, and is reduced during intervals of flow in the reverse direction. As the cycle is repeated, the less readily adsorbed component is concentrated in the first direction, while the more readily adsorbed component is concentrated in the reverse direction.

A "light" product, depleted in the more readily adsorbed component and enriched in the less readily adsorbed component, is then delivered from the second end of the adsorber. A "heavy" product enriched in the more strongly adsorbed component is exhausted from the first end of the adsorber. The light product is usually the desired product to be

purified, and the heavy product often a waste product, as in the important examples of oxygen separation over nitrogen-selective zeolite adsorbents and hydrogen purification. The heavy product (enriched in nitrogen as the more readily adsorbed component) is a desired product in the example of nitrogen separation over nitrogen-selective zeolite adsorbents. Typically, the feed is admitted to the first end of a adsorber and the light product is delivered from the second end of the adsorber when the pressure in that adsorber is elevated to a higher working pressure. The heavy product is exhausted from the first end of the adsorber at a lower working pressure. In order to achieve high purity of the light product, a fraction of the light product or gas enriched in the less readily adsorbed component is recycled back to the adsorbers as "light reflux" gas after pressure letdown, e.g. to perform purge, pressure equalization or repressurization steps.

The conventional process for gas separation by pressure swing adsorption uses two or more adsorbers in parallel, with directional valving at each end of each adsorber to connect the adsorbers in alternating sequence to pressure sources and sinks, thus establishing the changes of working pressure and flow direction. The basic pressure swing adsorption process also makes inefficient use of applied energy, because of irreversible expansion over the valves while switching the adsorbers between higher and lower pressures. More complex conventional pressure swing adsorption devices achieve some improvement in efficiency by use of multiple "light reflux" steps, both to achieve some energy recovery by pressure equalization, and also desirably to sequence the light reflux steps so that lower purity light reflux gas reenters the second end of the adsorbers define flow channels between adjacent sheets, formed either as stacked assemblies or as

spiral rolls, have been disclosed by Keefer (U.S. Patent No. 4,968,329 and U.S. Patent No. 5,082,473).

U.S. Pat. No. 4,968,329 discloses related gas separation devices with valve logic means to provide large exchanges of fresh feed gas for depleted feed gas. Such large feed exchanges may be required when concentrating one component as a desired product without excessively concentrating or accumulating other components, as in concentrating oxygen from feed air containing water vapor whose excessive concentration and accumulation would deactivate the adsorbent.

Siggelin (U.S. Patent No. 3,176,446), Mattia (U.S. Patent No. 4,452,612), Davidson and Lywood (U.S. Patent No. 4,758,253), Boudet et al (U.S. Patent No. 5,133,784), and Petit et al (U.S. Patent No. 5,441,559) disclose PSA devices using rotary adsorber configurations. Ports for multiple angularly separated adsorbers mounted on a rotor assembly sweep past fixed ports for feed admission, product delivery and pressure equalization. In this apparatus, the relative rotation of the ports provides the function of a rotary distributor valve. Another family of devices with stationary adsorbent beds and rotating multiport distributor valves have been disclosed by van Weenen (U.S. Patent No. 4,469,494), Hill et al (U.S. Patent Nos. 5,112,367; 5,268,021; RE035099), Schartz (U.S. Patent No. 5,632,804), Nemcoff et al (U.S. Patent Nos. 5,807,423; 5,814,130; 5,814,131; 5,820,656; 5,891,217), and Keefer et al (U.S. Patent No. 6,063,161). All of these prior art devices use multiple adsorbers operating sequentially on the same cycle, with multiport distributor rotary valves for controlling gas flows to, from and between the adsorbers.

The prior art includes numerous examples of pressure swing adsorption and vacuum swing adsorption devices with three adsorbers operating in parallel. Thus, Hay (U.S. Patent No. 4,969,935) and Kumar et al (U.S. Patent No. 5,328,503) disclose vacuum adsorption systems which do not achieve continuous operation of compressors and vacuum pumps connected at all times to one of the three adsorbers. Such operation is achieved in other three adsorber examples provided by Tagawa et al (U.S. Patent No.

4,781,735), Hay (U.S. Patent No. 5,246,676), and Watson et al (U.S. Patent No. 5,411,528), but in each of these latter examples there is some undesirable inversion of the ordering of light product withdrawal and light reflux steps so that process efficiency is compromised.

SUMMARY OF THE INVENTION

The present invention is intended to enable high frequency operation of pressure swing and vacuum swing adsorption processes, with high energy efficiency and with compact machinery of low capital cost. The invention applies in particular to air separation.

The invention provides an apparatus for PSA separation of a feed gas mixture containing a more readily adsorbed component and a less readily adsorbed component, with the more readily adsorbed component being preferentially adsorbed from the feed gas mixture by an adsorbent material under increase of pressure, so as to separate from the gas mixture a heavy product gas or exhaust gas enriched in the more readily adsorbed component, and a light product gas enriched in the less readily adsorbed component and depleted in the more readily adsorbed component. The apparatus includes compression machinery cooperating with three adsorbers mounted in a rotary PSA module.

Each adsorber has a flow path contacting adsorbent material between first and second ends of the flow path. When the adsorbent material is a nitrogen-selective zeolite and the feed gas is air, the light product gas will be enriched in oxygen (the desired product for life support) and the heavy product gas will be enriched in nitrogen (the waste exhaust which is engaged in relative rotation with first and second valve bodies to define rotary sealing faces of first and second valves adjacent respectively the first and second ends of the adsorber flow paths. In some preferred embodiments, the adsorber housing body is a rotor (the "adsorber rotor") which rotates while the first and second valve bodies together form the stator. In other preferred embodiments, the adsorber housing body is stationary, while the first and second valve bodies rotate to achieve the valving function. Fluid

transfer means are provided to provide feed gas to the first valve body, to remove exhaust gas from the first valve body, and to deliver light product gas from the second valve body.

The first valve admits feed gas to the first end of the adsorbers, and exhausts heavy product gas from the first end of the adsorbers. The second valve cooperates with the adsorbers to deliver light product gas from the second end of the adsorbers, to withdraw light reflux gas from the second end of the adsorbers, and to return light reflux gas to the second end of the adsorbers. The term 'light reflux" refers to withdrawal of light gas (enriched in the less readily adsorbed component) from the second end of the adsorbers via the second valve, followed by pressure let-down and return of that light gas to other adsorbers at a lower pressure via the second valve. The first and second valves are operated so as to define the steps of a PSA cycle performed sequentially in each of the adsorbers, while controlling the timings of flow at specified total pressure levels between the adsorbers and the compression machinery.

The PSA process of the invention establishes the PSA cycle in each adsorber, within which the total working pressure in each adsorber is cycled between a higher pressure and a lower pressure of the PSA cycle. The higher pressure is superatmospheric, and the lower pressure may conveniently either be atmospheric or subatmospheric. The PSA process also provides intermediate pressures between the higher and lower pressure. The compression machinery of the apparatus in general includes a feed gas compressor and a heavy product gas exhauster. The exhauster would be a vacuum pump when the lower pressure is subatmospheric. When the lower pressure is atmospheric, the exhauster could be an expander, or else may be replaced by throttle means to regulate countercurrent blowdown.

In the present invention, the feed compressor will typically supply feed gas for feed pressurization of the adsorbers to the first valve means. The exhauster will typically receive heavy product gas for countercurrent blowdown of the adsorbers from the first valve means.

A buffer chamber is provided to cooperate with the second valve. The buffer chamber provides the "light reflux" function of accepting a portion of the gas enriched in the second component as light reflux gas from a adsorber at the higher pressure and during cocurrent blowdown to reduce the pressure from the higher pressure, and then returning that gas to the same adsorber to provide purge at the lower pressure and then to provide light reflux pressurization to increase the pressure from the lower pressure. The light reflux function enables production of the light product with high purity.

The present invention performs in each adsorber the sequentially repeated steps within the cycle period as follows.

(A) Feed pressurization and production. Feed gas mixture is admitted to the first end of the adsorber during a feed time interval over approximately 1/3 of the cycle period (0T-T/3), commencing when the pressure within the adsorber is a first intermediate pressure between the lower pressure and the higher pressure, pressurizing the adsorber to the higher pressure (step A1), and then delivering light product gas from the second end (step A2) at a light product delivery pressure which is substantially the higher pressure less minor pressure drops due to flow friction.

(B)Withdraw from the second end a first light reflux gas enriched in the second component (preferably following step A2 of light product delivery) at approximately the higher pressure during a brief time interval at or near the end of step A (T/3).

(C) Equalization to buffer chamber.. While flow at the first end of the adsorber is stopped during a cocurrent blowdown time interval following step B, withdraw a second light reflux gas enriched in the second component as light reflux gas from the second end

(D) Withdraw a third light reflux gas from the second end as purge flow for another adsorber, during a brief time interval at approximately the end of step C (T/2).

(E) Countercurrent blowdown and exhaust. Exhaust a flow of gas enriched in the first component from the first end of the adsorber during an exhaust time interval (T/2-5T/6), in step E1 to depressurize the adsorber from the second intermediate pressure to the lower pressure, and then in step E2 transferring a flow of third light reflux gas from the second end of another adsorber undergoing step D to purge the adsorber at substantially the lower pressure while continuing to exhaust gas enriched in the first component as a heavy product gas.

(F) Equalization from buffer chamber. While flow at the first end of the adsorber is stopped, supply second light reflux gas from the buffer chamber to the second end of the adsorber. This increases the pressure of the adsorber from substantially the lower pressure to the second intermediate pressure.

(G) Admit a flow of first light reflux gas from the second end of another adsorber as backfill gas to increase adsorber pressure to the first intermediate pressure for the beginning of step A of the next cycle.

It will be appreciated by those skilled in the art that alternative light reflux flow patterns may be used. For example, delete steps B and G, or delay step B to follow step A rather than overlap step A so it acts as a pressure equalization step. With appropriate porting of the second valve, the apparatus of this invention may be used to implement the process steps of prior art cycles with three adsorbers, for example as prescribed in any of the above cited U.S. Patent Nos. 4,781,735; 4,969,935; 5,246,676; 5,328,503; and 5,411,528.

The process may be controlled by varying the cycle frequency so as to achieve desired purity, recovery and flow rates of the light product gas. Alternatively, the feed flow rate and the light product flow rate may be adjusted at a given cycle frequency, so as to achieve desired light product purity. Preferably, light product flow rate is adjusted to

maintain delivery pressure in a light product receiver, by simultaneously varying feed compressor drive speed and the rotational frequency of the PSA module.

In vacuum embodiments, the first intermediate pressure and second intermediate pressure are typically approximately equal to atmospheric pressure, so that the lower pressure is subatmospheric. Alternatively, the lower pressure may be atmospheric. In air purification applications, the first component is an impurity gas or vapor, the gas mixture is air containing the impurity, and the light product is purified air. In air separation applications, the first component is nitrogen, the second component is oxygen, the adsorbent material includes a nitrogen-selective zeolite, the gas mixture is air, the heavy product or exhaust gas is nitrogen-enriched air, and the light product is enriched oxygen. In the following disclosure, the light product may also be referred to as simply the product, while the heavy product may be referred to as the exhaust gas.

In preferred embodiments of the invention, the adsorbent is supported in the form of layered adsorbent or "adsorbent laminate," formed from flexible adsorbent sheets. The adsorbent sheets are thin sheets of adsorbent with a composite reinforcement, or as an inert sheets or foil coated with the adsorbent. Flow channels are established by spacers forming parallel channels between adjacent pairs of sheets. The channel width between adjacent adsorbent sheets of the experimental adsorbers has been in the range of 50% to 100% of the adsorbent sheet thickness. This "adsorbent laminate" configuration has much lower pressure drop than packed adsorbers, and avoids the fluidization problem of packed adsorbers. The adsorbent sheets are typically in the range of 100 to 175 microns thick. The sheet-laminate provides desirable compliance to accommodate stacking or rolling errors, and spacer systems provide the necessary stability against unrestrained deflections or distortions that would degrade the uniformity of the flow channels between adjacent layers of adsorbent sheet.

BRIEF DESCRIPTION OF THE DRAWINGS

The preferred embodiments of the present invention will now be described, with reference to the drawings in which:

Fig. 1 shows a simplified schematic of a rotary vacuum oxygen concentrator with three adsorbers, a feed air compressor, and an exhaust vacuum pump.

Fig. 2 shows a rotary positive pressure oxygen concentrator with three adsorbers, with each adsorber communicating to a feed air compressor.

Fig. 3 shows a more detailed schematic of a rotary vacuum oxygen concentrator apparatus with three adsorbers, with each adsorber communicating to a feed air compressor, and an exhaust vacuum pump.

Fig. 4 shows the gas flow pattern and pressure pattern associated with an adsorber of the apparatus of Fig. 1.

Fig. 5 shows the pressure pattern for all three adsorbers, in the format to which the invention shall be applied.

Fig. 6 shows a cross section of a module. Note that each of the two valve ends is shown at a different point in the cycle.

Figs. 7 to 10 show closer views of the stator and rotor valve faces.

Fig. 11 shows an embodiment similar to Fig. 1, but with the adsorber housing body stationary while the first and second valve bodies rotate.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figs. 1, 2 and 3

An oxygen concentrator according to the invention has three adsorbers 1, 2 and 3 in apparatus 4 (the rotary PSA module); the adsorbers having respectively first ends 5, 6 and 7, and second ends 8, 9 and 10. The PSA cycle is performed in the three adsorbers, with a phase shift of 120° between the adsorbers in the sequence of adsorbers 1, 2 and then 3. Figures 1 and 3 show vacuum assisted embodiments, while Figure 2 shows a positive pressure embodiment without vacuum assist.

Apparatus 4 includes a rotary adsorber module 20 including first valve body 22, adsorber housing body 23 and second valve body 24. Relative rotation is established between the adsorber housing body 23 and the first and second valve bodies, with fluid sealing engagement between the adsorber housing body and the first valve body across a first valve face 37, with fluid sealing engagement between the adsorber housing body and the second valve body across a second valve face 38. In this embodiment and those shown in figures 2 and 3, the adsorber housing body 23 is rotating and hence may also be referred to as rotor 23, while the first and second valve bodies are stationary and together constitute stator 21 of module 20.

In the adsorber housing body 23, adsorber body ports 250, 251 and 252 provide fluid communication between adsorber first ends 5, 6 and 7 to the first valve face 37, while adsorber body ports 501, 501 and 503 provide fluid communication between adsorber second ends 8, 9 and 10 to the second valve face 38. [illegible] communication to first valve face 37 for feed and exhaust (or heavy product) functions. Compressor 11 or blower 11 is provided to draw feed air through inlet filter 12 from feed inlet 201, and to supply compressed feed air to port 201 through conduit 614, which serves as feed fluid transfer means cooperating with the first valve body. In Figures 1 and 3, an exhauster 13 or vacuum pump 13 is provided to exhaust nitrogen enriched air

from port 202 by conduit 615, which serves as exhaust fluid transfer means cooperating with the first valve body. Motor 14 is provided to drive compressor 11 by shaft 15 and vacuum pump 13 by shaft 16.

Functional ports 30, 31, 32, 33, 34, 35 and 36 in the second valve body 22 respectively provide fluid communication to second valve face 38 for the functions of light product delivery, first light reflux exit, second light reflux exit, third light reflux exit, third light reflux return, second light reflux return, and first light reflux return. The light product (e.g. enriched oxygen or purified air) is delivered from port 30 by conduit 616, which serves as light product fluid transfer means cooperating with the first valve body. The light product is delivered by conduit 616 to a product delivery valve 25 and thence to product delivery conduit 203. Valve 25 serves to control product flow and/or to regulate the PSA cycle working pressure in port 30.

First light reflux exit port 31 and first light reflux return port 36 are connected by first light reflux conduit 26 which provides the purge function of the PSA cycle. Second light reflux exit port 32 and second light reflux return port 35 are connected by second light reflux conduit 28 which provides the equalization function of the PSA cycle through buffer chamber 29 in conduit 28. Third light reflux exit port 33 and third light reflux return port 34 are connected by third light reflux conduit 27 which provides the product repressurization or backfill function of the PSA cycle. Fixed or adjustable throttle restrictors or orifices 26', 28', and 27' are included in each of the light reflux conduits respectively 26, 28 and 27 to achieve pressure let-down of light reflux flows in each of the three light reflux stages of the PSA process.

Figure 2 shows a rotary positive pressure PSA oxygen concentrator. In this embodiment, the exhauster 13 is replaced with exhaust conduits incorporating throttle orifices 17 and 18 for controlled pressure release during countercurrent blowdown, and a low pressure exhaust conduit 19 exhausting directly to atmosphere. Throttle orifice 17 may be more restrictive than throttle orifice 18 in order to support an initially larger pressure drop during the early part of a countercurrent blowdown step, while throttle 18 would support

a smaller pressure drop in the later part of a countercurrent blowdown step. Alternatively, throttle orifices 17 and 18 may be combined into a single orifice, which may be provided by tapering port 202 so as to be very restrictive at the beginning of a countercurrent blowdown step and ultimately fully open at the end of the countercurrent blowdown step.

Another alternative embodiment for a positive pressure PSA oxygen concentrator (now based on Fig. 1) is to provide exhauster 13 as an expander 13 for energy recovery during the countercurent blowdown step, with expander 13 assisting motor 14 to drive compressor 11.

Figure 3 shows a particular embodiment of the compressor and vacuum pump. The filtered air from inlet air filter 12 enters a compressor intake manifold 44 to be inducted by an inlet check valve 45 into one of two opposed compressor cylinders 41 cooperating with pistons 41', and then is delivered by a discharge check valve 40 and compressor exhaust manifold 43 to conduit 614 transferring the compressed feed air to feed port 201. Similarly, exhaust nitrogen-enriched or impurity laden air is withdrawn by conduit 615 from exhaust port 202 into vacuum pump intake manifold 47, by a vacuum pump inlet check valve 49 into one of two opposed vacuum pump cylinders 42 cooperating with pistons 42', and then is delivered by a vacuum pump delivery check valve 48 via exhaust manifold 46 to exhaust conduit 202. It will be appreciated that pistons 41' and 42' are cyclic volume displacement means, which could equivalently be provided as reciprocating pistons or reciprocating diaphragms.

Each pair of opposed pistons 41' and 42' is driven in reciprocating motion by a reciprocating crank mechanism 50 and 51 respectively, with drive couplings 52 and 53 to motor 14. As will be made clear from the following description of the PSA cycle, a preferred embodiment will have the reciprocating phase of cranks 50 and 51 offset by approximately or exactly 90°. A very simple and compact realization of this emodiment is achieved by providing each of the crank mechanisms 50 and 51 as a Scotch yoke, and then mounting cylinders 41 and 42 with 90° offset of their reciprocating axes so that both

Scotch yokes 50 and 51 can be driven by a single crank throw (e.g. a crank pin or an eccentric) on a crankshaft coupled to motor 14. Hence, drive couplings 52 and 53 can be consolidated into a single crank driving reciprocation in quadrature of all four cylinders. The crankshaft axis of rotation and the reciprocating axes of cylinders 41 and 42 will then all be mutually orthogonal.

If the pistons are reciprocating at a frequency much greater than the frequency of the rotor, then the system is simply a piston compressor embodiment as in Figure 1. However, an alternative is to synchronize piston reciprocation in both frequency and phase with the PSA cycle so that a complete feed step "A1" is accomplished by a simple stroke of a compressor piston, and an exhaust step "E1" is accomplished by a single stroke of a vacuum pump piston. The reciprocating frequency of the compressor and vacuum is set to be exactly 1.5 times the frequency of the cycle. Pressure variations within the PSA cycle are thus coordinated with those within the compressor and vacuum pump cylinders, enabling an improvement in efficiency and substantially eliminating pressure and flow pulsations extraneous to the PSA cycle itself.

The consolidation of reciprocating crank drives 50 and 51 as a perpendicularly reciprocating pair of Scotch yokes on a single crank pin will be useful for use in manual drives (manual or foot pedal power with a pulley linkage between the motor and the rotor). The manual apparatus could be used in emergency situations such as at high altitude mountain survival or rescue, and for survival while awaiting rescue in confined spaces such as in sunken submarines or in collapsed underground coal mines.

Furthermore, power consumption is reduced since the compressor 11 and vacuum pump 13 each follow the changing pressure of the adsorber for respectively feed pressurization and countercurrent blowdown steps. Thus, the average working pressure across each of the compressor 11 and vacuum pump 13 is much less than the maximum working pressure.

Fig. 4 and 5

Figures 4 and 5 show the cyclic variation of the working gas pressure at the first ends of the adsorbers over a cycle period corresponding to 360° rotation of the rotary PSA apparatus of Figures 1 and 3. Figure 4 shows the cycle for adsorber 1, while Figure 5 shows the cycle for all three adsorbers. Note that the three adsorbers charted in Figure 5 are 120° out of phase from each other.

The horizontal axis 100 of Fig. 4 represents angular position of the rotary valve faces, in 30° fractions of the cycle period. The vertical axis 101 represents the working pressure in adsorber 1.

Curve 102 shows the position variation of the flow path through the valve face plates, with the system pressure cycling between higher pressure 104 and the lower pressure 103. 105 and 110 are the intermediate pressures in the cycle.

The cycle is divided into six process steps.

1. The feed pressurization step extends over the feed time interval from positions 0° degrees to 120° of the cycle period on horizontal axis 100. At the beginning of the cycle (0°), feed gas is fed through an inlet filter to a compressor 11 and the first end of the adsorbers, bringing the system to its higher pressure 104. The feed step includes feed from first intermediate pressure 105 to the higher pressure 104. Typically, the first intermediate pressure is nominally atmospheric pressure.

2. A and B: Feed with production and production for backfill (pressurization with gas enriched in the second component). In step A, between 60° and 90°, light product gas is withdrawn from the second end of adsorber 1 through the light product port. Between 90° and 120° (step B), light reflux is withdrawn from the second end of adsorber 1 to backfill adsorber 2.

3. C and D: The cocurrent blowdown step extends over the cocurrent blowdown interval from 120° to 180°. Between 120 ° and 150° (step C), light reflux gas is withdrawn from the second end of adsorber 1 to equalize the buffer chamber 29. During 150 ° to 180° (step D), light reflux gas is removed from the second end of adsorber 1 to purge adsorber 3. The cocurrent blowdown step begins at substantially the higher pressure 104 and ends at a second intermediate pressure 110, which typically may be approximately equal to the first intermediate pressure 105.

4. E1: The countercurrent blowdown (to exhaust) interval E1 extends from 180° to 270°, bringing the system down from second intermediate pressure 110 to its lower pressure 103.

5. E2: Purge to exhaust. During step E2, gas is removed between 270 °-300° from the second end of adsorber 2 to purge adsorber 1. Exhaust is removed from the first end of adsorber 1 from 270 °-300 °.

6. F and G: The countercurrent re-pressurization step extends from 300° to 360°. The cycle between 300 °-330° (step F) equalizes the second end of adsorber 1 from the buffer chamber 29. The cycle between 330 °-360° (step G) is applied to backfilling adsorber 1 from adsorber 3.

The following sequence table illustrates the above sequence description.

Table 1. Sequence Table

Step	Time	Adsorber 1			Adsorber 2			Adsorber 3		
		1st Stator valve	2nd Stator Valve	State	1st Stator valve	2nd Stator Valve	State	1st Stator valve	2nd Stator Valve	State
1	0-30	F to H1	Closed	Feed pressurization	Closed	L2 to B	Provide buffer gas	H3 to E	Closed	Exhaust
2	30-60	F to H1	Closed	Feed pressurization	Closed	L2 to L3	Provide purge	H3 to E	L2 to L3	Purge
3	60-90	F to H1	L1 to P	Production	H2 to E	Closed	Exhaust	Closed	B to L3	Pressurization from buffer
4	90-120	F to H1	L1 to L3	Provide product pressurization	H2 to E	Closed	Exhaust	Closed	L1 to L3	Product pressurization
5	120-150	Closed	L1 to B	Provide buffer gas	H2 to E	Closed	Exhaust	F to H3	Closed	Feed pressurization
6	150-180	Closed	L1 to L2	Provide purge	H2 to E	L1to L2	Purge	F to H3	Closed	Feed pressurization
7	180-270	H1 to E	Closed	Exhaust	Closed	B to L2	Pressurization from buffer	F to H3	L3 to P	Production
8	210-240	H1 to E	Closed	Exhaust	Closed	L3 to L2	Product pressurization	F to H3	L3 to L2	Provide product pressurization
9	240-270	H1 to E	Closed	Exhaust	F to H2	Closed	Feed pressurization	Closed	L3 to B	Provide buffer gas
10	270-300	H1 to E	L3 to L1	Purge	F to H2	Closed	Feed pressurization	Closed	L3 to L1	Provide purge
11	300-330	Closed	B to L1	Pressurization from buffer	F to H2	L1 to P	Production	H3 to E	Closed	Exhaust
12	330-360	Closed	L2 to L1	Product pressurization	F to H2	L1 to L2	Provide product pressurization	H3 to E	Closed	Exhaust

<u>Fig. 6</u>

Figure 6 shows an axial section of a rotary PSA module 20 according to the invention. Components are identified with the same reference numerals and nomenclature as in Figs. 1 – 3. Transverse cross sections 212, 213 and 214 of module 20 are shown in Figures 7 through 10.

Adsorber housing body 23 is engaged in relative rotation with first valve body 22 and second valve body 24. In this embodiment, adsorber housing body 23 is a rotor 23 with rotary axis 211. Rotor 23 is driven by a motor 206 coupled to gear reducer 209, which is in turn attached to the drive coupling 210. Motor 206 may also be the motor 14 which drives the compressor and exhauster. Motor 14 may be a double-shafted motor with one

shaft extension driving the compressor and exhauster, and the other shaft extension driving the rotary PSA module.

The adsorber housing body or rotor 23 has a first valve face plate 37' defining first valve face 37, and a second valve face plate 38' defining first valve face 38. The adsorbers (e.g. adsorber 1) are shown as spirally wound layered laminates of adsorbent sheet material with spacers, as further illustrated in Figs. 8a and 8b. The adsorbers are spirally wound or wrapped around a cylindrical tube mandrel 150 whose interior volume is conveniently used as buffer chamber 29. The mandrel 150 is supported on first and second end plugs 151 and 152, which respectively carry first and second valve face plates 37' and 38', and an outer housing sleeve 207 containing the adsorbers. The first end plug 151 has a stub shaft 153 coupled to drive shaft 210. The second end plug 152 has a hollow stub shaft 154 which provides fluid communication between buffer chamber 29 and the second light reflux conduit 26 in the second valve body 24. The second light reflux conduit 26 is narrow enough to serve itself as a nonadjustable throttle restrictor 26' so as to achieve pressure letdown during equalization from an adsorber to the buffer chamber, and then from the buffer chamber to another adsorber.

The first and second valve face plates of the rotor are shown in Figs. 7a and 10a, while the porting of the first and second valve bodies in valve faces 37 and 38 is shown in Figs. 7b and 10b. In Fig. 6, the first valve is drawn to illustrate in the feed step of the PSA cycle, while the second valve is drawn to illustrate the second light reflux exit step (equalization to buffer) which would in fact be delayed after the feed step.

Fig. 7

Figure 7a shows the first rotor valve face 37. Apertures 250 (H1), 251 (H2) and 252 (H3) on the valve face plate facilitate the flow action of gases from one adsorber to another corresponding to the sequencing defined in the Figure 4/5 description. H1, H2 and H3 correspond to the first rotor valve openings for adsorbers 1,2 and 3, respectively.

Figure 7b shows the first stator valve face 22. Feed enters through feed port aperture 201 and exhaust exits through exhaust port aperture 202.

Figs. 7a and 7b are opposed views of transverse cross section 212 of Figure 6.

Fig. 8a and 8b

Figure 8a shows the laminate adsorbers at transverse cross section 213 of Figure 6. The three adsorbers may be formed as a single spiral roll of adsorbent sheet 160 with spacers 161 between the layers to define flow channels 162. The three adsorbers 1, 2 and 3 are respectively divided within the single spiral roll by partitions 301 that are formed by impregnating a sealant in a narrow zone of the laminate adsorber to substantially prevent lateral fluid communication across each such partition zone 301. The partitions 301 are positioned at substantially 120° intervals. The spiral roll is wrapped around mandrel 150, and to prevent bypass flow may be sealed by an appropriate sealant within housing sleeve 207. Discontinuities in the spiral roll at the beginning and end of the roll may desirably be accommodated with one of the partition zones, as shown. Buffer chamber 29 is located in the center of the rotor 23. Arrow 302 shows the direction of rotation of the adsorber assembly.

Figure 8b shows the adsorbers formed by wrapping distinct rectangular adsorbent sheets with spacers to from each adsorber. The partitions 301 are now provided as solid sealing members between the adsorbers, extended from mandrel 150 to housing sleeve 207. The width of the adsorbent sheets is less than 1/3 of the circumference by the width of the partition sealing member 301.

Fig. 9

Figure 9 shows the rotor valve face cross section 213 of Figure 6. The dashed slots 401 correspond to the relative positions of the adsorbers in the rotor assembly. Ports 402, 403 and 404 represent the rotor port apertures 501, 502 and 503 (as seen in Figure 10a) or 250, 251 and 252 (as seen in Figure 7a), depending on which rotor face is being considered.

Fig. 10

Figure 10a shows the second rotor valve face 38. Figure 10b shows the second stator valve face 24. Both figures are taken at cross section 214 on Figure 6. Each of the apertures 501 (L1), 502 (L2) and 503 (L3) on the face plate facilitate the flow action of gases from one adsorber to another corresponding to the sequencing defined in the Figure 4/5 description. L1, L2 and L3 correspond to the second rotor valve openings for adsorbers 1, 2 and 3, respectively.

Ports 31, 32, and 33 are first, second and third light reflux exit ports, respectively, and ports 36, 35 and 34 are first, second and third light reflux return ports, respectively.

Fig. 11

Figure 11 shows an embodiment 600 similar to Fig. 1, but with the adsorber housing body stationary while the first and second valve bodies rotate.

The adsorbers are mounted at equal angular spacing in an adsorber housing body 23, which is engaged in relative rotation with first and second valve bodies 611 and 613 to define rotary sealing faces of first and second valves adjacent respectively the first and second ends of the adsorber flow paths. There is fluid sealing engagement between the adsorber housing body and respectively the first and second valve bodies. The adsorber housing body 23 is stationary, while the first and second valve bodies 611 and 613 rotate to achieve the valving function. Fluid transfer means are provided to provide feed gas to the first valve body 611, to remove exhaust gas from the first valve body 611, and to deliver light product gas from the second valve body 613.

In this embodiment, the first valve body has rotary fluid seals 604 and 605 which define the feed fluid transfer chamber 601 as fluid transfer means to provide feed gas to the first valve body between the first valve body 611 and the casing 612. The feed gas is introduced into chamber 601 by conduit 614.

The first valve body also has rotary fluid seals 605 and 606 which define the exhaust fluid transfer chamber 602 between the first valve body 611 and the casing 612. Chamber 602 is fluid transfer means to remove exhaust gas from the first valve body and into conduit 615.

The second valve body 613 has rotary fluid seals 606' and 608 that define a product fluid transfer chamber 610 between the second valve body 613 and the casing 612. Chamber 610 is fluid transfer means to deliver light product gas from the second valve body into conduit 616.

Fig. 11 shows a rotary drive shaft for each valve body that drives rotation of the first and second valves at the cycle frequency and in coordinated angular phase, with shaft 603 driving first valve body 611 and shaft 609 driving second valve body 613. If desired, with a coaxial installation of the first and second rotary valves, shafts 603 and 609 may be combined as a single shaft (e.g. penetrating the adsorber housing body) to drive both valve bodies. The shafts are driven to rotate by valve drive means 607, such as a valve drive motor or an extension shaft from a gear reducer coupled to the compressor drive motor.

CLAIMS

1. Process for pressure swing adsorption separation of a feed gas mixture containing a more readily adsorbed component and a less readily adsorbed component, with the more readily adsorbed component being preferentially adsorbed from the feed gas mixture by an adsorbent material under increase of pressure, so as to separate from the feed gas mixture a heavy product gas enriched in the more readily adsorbed component and a light product gas enriched in the less readily adsorbed component; providing for the process a cooperating set of three adsorbers within a rotor and equally spaced angularly about the axis defined by rotation of the rotor relative to a stator, and rotating the rotor so as to generate within each adsorber cyclic variations of pressure and flow at a cyclic period defined by the frequency of rotation along a flow path contacting the adsorbent material between first and second ends of the adsorber, the cyclic variations of pressure extending between a higher pressure and a lower pressure of the process; rotating the rotor so that the first ends of the adsorbers successively communicate to feed and exhaust ports provided in a first valve surface between the rotor and the stator, and the second ends of the adsorbers successively communicate to a light product port, to light reflux exit ports and to light reflux return ports provided in a second valve surface between the rotor and the stator; the process including for each of the adsorbers in turn:

(a) supplying feed gas mixture at a feed pressure through the feed port to the adsorber over a feed interval which is substantially 1/3 of the cycle period so as to pressurize the adsorber to substantially the higher pressure, and then to deliver light product gas from the light product port at substantially the higher pressure less flow frictional pressure drops,

(b) withdrawing light reflux gas enriched in the less readily adsorbed component from the light reflux exit ports, in part to depressurize that adsorber after the feed interval,

(c) withdrawing second product gas at an exhaust pressure through the exhaust port from the adsorber over an exhaust interval which is substantially 1/3 of the cycle period so as to depressurize that adsorber to substantially the lower pressure while delivering the second product gas,

(d) returning light reflux gas enriched in the less readily adsorbed component from the light reflux return ports so as to purge the adsorber in the latter part of the exhaust interval and then to partially repressurize the adsorber prior to the next feed interval,

so that feed gas is continuously supplied to substantially one adsorber at time, and exhaust gas is continuously removed from substantially one adsorber at a time.

2. The process of claim 1, with a number of steps (b) for withdrawing light reflux gas from an adsorber, and an equal number of steps (c) for returning that light reflux gas to an adsorber.

3. The process of claim 2, further performing pressure let-down on each light reflux gas after being withdrawn and before being returned.

4. The process of claim 2, withdrawing light reflux gas from an adsorber and directly returning that light reflux gas to another adsorber whose cyclic phase is 120° apart.

5. The process of claim 2, withdrawing light reflux gas from an adsorber, delivering that light reflux gas to a buffer chamber, and then later returning that light reflux gas from the buffer chamber to another adsorber whose cyclic phase is 120° apart.

6. Process for pressure swing adsorption separation of a feed gas mixture containing a more readily adsorbed component and a less readily adsorbed component, with the more readily adsorbed component being preferentially adsorbed from the feed gas mixture by an adsorbent material under increase of pressure, so as to separate from the feed gas mixture a heavy product gas enriched in the more readily adsorbed component and a light product gas enriched in the less readily adsorbed

component; providing for the process a cooperating set of three adsorbers within a rotor and equally spaced by 120° angular separation about the axis defined by rotation of the rotor relative to a stator, and rotating the rotor so as to generate within each adsorber cyclic variations of pressure and flow at a cyclic period defined by the frequency of rotation along a flow path contacting the adsorbent material between first and second ends of the adsorber, the cyclic variations of pressure extending between a higher pressure and a lower pressure of the process; rotating the rotor so that the first ends of the adsorbers successively communicate to feed and exhaust ports provided in a first valve surface between the rotor and the stator, and the second ends of the adsorbers successively communicate to a light product port, to first, second and third light reflux exit ports and to first, second and third light reflux return ports provided in a second valve surface between the rotor and the stator; the process including for each of the adsorbers in turn the following cyclical steps in sequence:

(a) supplying feed gas mixture at a feed pressure through the feed port to the adsorber over a feed interval which is substantially 1/3 of the cycle period so as to pressurize the adsorber to substantially the higher pressure, and then to deliver light product gas from the light product port at substantially the higher pressure less flow frictional pressure drops,

(b) withdrawing a first light reflux gas enriched in the less readily adsorbed component from the first light reflux exit port at about the end of the feed interval,

(c) withdrawing a second light reflux gas enriched in the less readily adsorbed component from the first light reflux exit port to depressurize that adsorber after the feed interval,

(d) withdrawing a third light reflux gas enriched in the less readily adsorbed component from the first light reflux exit port to further depressurize that adsorber,

(e) withdrawing second product gas at an exhaust pressure through the exhaust port from the adsorber over an exhaust interval which is substantially 1/3 of the cycle period so as to further depressurize that adsorber to substantially the lower pressure while delivering the second product gas,

(f) returning third light reflux gas from the third light reflux return port which is receiving that gas after pressure letdown from another adsorber (whose phase is leading by 120°), so as to purge the adsorber in the latter part of the exhaust interval,

(g) returning second light reflux gas from the second light reflux return port so as to partially repressurize the adsorber prior to the next feed interval,

(h) returning first light reflux gas from the first light reflux return port which is receiving that gas after pressure letdown from another adsorber (whose phase is lagging by 120°), so as to further repressurize the adsorber prior to the next feed interval, and

(i) cyclically repeating the above steps,

so that feed gas is continuously supplied to substantially one adsorber at time, and exhaust gas is continuously removed from substantially one adsorber at a time.

7. Process for pressure swing adsorption separation of a feed gas mixture containing a more readily adsorbed component and a less readily adsorbed component, with the more readily adsorbed component being preferentially adsorbed from the feed gas mixture by an adsorbent material under increase of pressure, so as to separate from the feed gas mixture a heavy product gas enriched in the more readily adsorbed component and a light product gas enriched in the less readily adsorbed component; providing for the process a cooperating set of three adsorbers, and generating within each adsorber cyclic variations of pressure and flow at a cyclic period defined by the frequency of rotation along a flow path contacting the

adsorbent material between first and second ends of the adsorber and with the cyclic phase 120° staggered for each adsorber. the cyclic variations of pressure extending between a higher pressure and a lower pressure of the process; the process including for each of the adsorbers in turn the following cyclical steps in sequence:

(a) supplying feed gas mixture to the first end of the adsorber over a feed interval which is substantially 1/3 of the cycle period so as to pressurize the adsorber to substantially the higher pressure. and then to deliver light product gas from the second end of the adsorber at substantially the higher pressure less flow frictional pressure drops,

(b) withdrawing a first light reflux gas enriched in the less readily adsorbed component from the second end of the adsorber at about the end of the feed interval,

(c) withdrawing a second light reflux gas enriched in the less readily adsorbed component from the second end of the adsorber to depressurize that adsorber after the feed interval. and delivering the second light reflux gas to a buffer chamber,

(d) withdrawing a third light reflux gas enriched in the less readily adsorbed component from the second end of the adsorber to further depressurize that adsorber,

(e) withdrawing second product gas at an exhaust pressure from the first end of the adsorber over an exhaust interval which is substantially 1/3 of the cycle period so as to further depressurize that adsorber to substantially the lower pressure while delivering the second product gas,

(f) supplying third light reflux gas from another adsorber (whose phase is leading by 120°) to the second end of the adsorber, so as to purge the adsorber during the latter part of the exhaust interval,

(g) supplying second light reflux gas from the buffer chamber to the second end of the adsorber, so as to partially repressurize the adsorber prior to the next feed interval,

(h) supplying third light reflux gas from another adsorber (whose phase is leading by 120°) to the second end of the adsorber, so as to further repressurize the adsorber prior to the next feed interval, and

(i) cyclically repeating the above steps,

while feed gas is continuously supplied to substantially one adsorber at time, and exhaust gas is continuously removed from substantially one adsorber at a time.

8. Apparatus for pressure swing adsorption separation of a gas mixture containing a more readily adsorbed component and a less readily adsorbed component, with the more readily adsorbed component being preferentially adsorbed from the gas mixture by an adsorbent material under increase of pressure between a lower pressure and a higher pressure, so as to separate from the gas mixture a heavy product gas enriched in the more readily adsorbed component and a light product gas depleted in the more readily adsorbed component; the apparatus including an adsorber rotor cooperating with a stator mutually defining the rotational axis of the rotor and with rotor drive means to rotate the rotor at a rotational period which defines a pressure swing adsorption cycle period, the rotor containing a cooperating set of three adsorbers equally angularly spaced about the rotational axis, each adsorber having a flow path [illegible] communicating by first apertures to a first valve surface between the rotor and the stator, and the second ends of the adsorbers communicating by second apertures to a second valve surface between the rotor and the stator; the first valve surface having feed and exhaust

ports engaging successively in fluid communication with the first apertures, and the first valve surface having a light product port, and first, second and third light reflux exit ports and first second and third light reflux return ports engaging successively in fluid communication with the second apertures: the apparatus further including feed supply means communicating to the feed port and second product exhaust means communicating to the exhaust port: the first and third light reflux exit ports communicating to directly to the first and third light reflux return ports respectively, and the second light reflux exit port communicating to a buffer chamber communicating in turn to the second light reflux return port: and the angular positions and widths of the ports and apertures being configured so that for each adsorber in sequence the following steps are performed:

(a) the first aperture of the adsorber is opened to the feed port through which feed gas mixture is supplied by the feed supply means over a feed interval of substantially 1/3 of the cycle period so as to pressurize the adsorber to substantially the higher pressure, while the second aperture of the adsorber is then opened to the light product port in the feed interval so as to deliver light product gas at substantially the higher pressure less flow frictional pressure drops,

(b) the second aperture of the adsorber is opened sequentially to the first, second and third light reflux exit ports so as to deliver light reflux gas enriched in the less readily adsorbed component and to depressurize the adsorber after the feed interval,

(c) the first aperture of the adsorber is opened to the exhaust port through which second product gas is exhausted by the second product exhaust means at an exhaust pressure over an exhaust interval which is substantially 1/3 of the cycle period so as to depressurize that adsorber to substantially the lower pressure and to deliver the second product gas,

(d) the second aperture of the adsorber is opened sequentially to the third, second and first light reflux return ports so as to purge the adsorber in the latter part of the exhaust interval and then to partially repressurize the adsorber prior to the next feed interval.

9. The apparatus of claim 8, further including sealing means in the first and second valve surfaces of the stator so as to limit gas leakage from and between the ports in those valve faces.

10. The apparatus of claim 8, in which the adsorber rotor includes a central core which is cylindrical and concentric with the axis.

11. The apparatus of claim 10, in which the central core is hollow and contains the buffer chamber which communicates to the second light reflux exit and return ports.

12. The apparatus of claim 8, in which the adsorbers are provided from layered adsorbent sheets, the sheets being formed of adsorbent material and a reinforcement material, with spacers between the sheets to establish flow channels between adjacent pairs of sheets.

13. The apparatus of claim 12, the adsorbers being installed as angularly spaced adsorber packs within the rotor and between the first and second valve faces, with the adsorbent sheets as sheets layered with flow channels therebetween to form the pack, and with the width of the sheets being not more than about 1/3 of the circumference of the central core.

14. The apparatus of claim 13, in which the adsorber rotor includes a central core which is cylindrical and concentric with the axis, and with the three adsorber packs positioned at equal angular intervals around the central core of the rotor, and with sealing partitions between the packs.

15. The apparatus of claim 8, in which the adsorber rotor includes a central core which is cylindrical and concentric with the axis, an adsorbent sheet formed of adsorbent material and a reinforcement material is rolled with spacers in a spiral roll about the central core so that the spacers define flow channels between adjacent layers of the roll, and lateral sealing means are provided at 120° angular intervals in the spiral roll so as to define the three adsorbers within the spiral roll.

16. The apparatus of claim 15, in which the lateral sealing means are provided by impregnating the spiral rolls with an inert scalant at 120° angular intervals.

17. The apparatus of claim 8, with means for light reflux pressure let-down of gas withdrawn from a light reflux exit port before return that gas to a light reflux return port.

18. The apparatus of claim 17, in which the means for light reflux pressure let-down is an orifice.

19. The apparatus of claim 8, in which the feed supply means is a compressor.

20. The apparatus of claim 19, in which the compressor supplies feed gas at a pressure which varies in accordance with pressurization of each adsorber during the feed interval.

21. The apparatus of claim 20, in which the compressor has two compression chambers in opposed phase, the volume of the compression chambers is cyclically varied by operation of a compressor drive means at a cyclic period which is 2/3 of the rotational period of the adsorber rotor, and the compressor drive means is synchronized with the adsorber rotor drive means so that one compression chamber supplies feed gas to an adsorber over its feed interval, and the other compression chamber supplies feed gas to the next adsorber over its feed interval.

22. The apparatus of claim 20, in which the compressor drive means and the adsorber rotor drive means are operated by a single motor.

23. The apparatus of claim 8, in which the exhaust means includes an orifice cooperating with the exhaust port so as to achieve pressure letdown to approximately the lower pressure of second product gas from a depressurizing adsorber during the early part of the exhaust interval for that adsorber.

24. The apparatus of claim 8, in which the exhaust means is a vacuum pump.

25. The apparatus of claim 24, in which the vacuum pump has two pump chambers in opposed phase, the volume of the pump chambers is cyclically varied by operation of a vacuum pump drive means at a cyclic period which is 2/3 of the rotational period of the adsorber rotor, and the vacuum pump drive means is synchronized with the adsorber rotor drive means so that one pump chamber exhausts second product gas from an adsorber over its exhaust interval, and the other pump chamber exhausts second product gas from the next adsorber over its exhaust interval

26. The apparatus of claim 25, in which the vacuum pump drive means and the adsorber rotor drive means are operated by a single motor.

27. The apparatus of claim 21 and 25, in which the compressor drive means, the vacuum pump drive means and the adsorber rotor drive means are operated by a single motor.

28. The apparatus of claim 27, in which the motor is operated at variable speed to adjust the light product flow and purity according to demand.

29. The apparatus of claim 21 and 25, in which the compressor drive means, the vacuum pump drive means and the adsorber rotor drive means are operated by a manual or pedal crank.

30. The apparatus of claim 21 and 25, in which the cyclic phases of the compression chambers and pump chambers are separated by 90°.

31. The apparatus of claim 27, in which the feed gas mixture is air, the adsorbent material includes a nitrogen-selective zeolite, and the light product is enriched oxygen.

32. Process for pressure swing adsorption separation of a feed gas mixture containing a more readily adsorbed component and a less readily adsorbed component, with the more readily adsorbed component being preferentially adsorbed from the feed gas mixture by an adsorbent material under increase of pressure, so as to separate from the feed gas mixture a heavy product gas enriched in the more readily adsorbed component and a light product gas enriched in the less readily adsorbed component; providing for the process a co-operating set of three adsorbers within an adsorber housing body cooperating with first and second valve bodies and in relative rotation thereto, the adsorbers being equally spaced angularly about the axis defined by the relative rotation between the adsorber housing body and the first and second valve bodies, and establishing the relative rotation so as to generate within each adsorber cyclic variations of pressure and flow at a cyclic period defined by the frequency of rotation along a flow path contacting the adsorbent material between first and second ends of the adsorber, the cyclic variations of pressure extending between a higher pressure and a lower pressure of the process; and establishing the relative rotation so that the first ends of the adsorbers successively communicate to feed and exhaust ports provided in a first valve surface between the adsorber housing body and the first valve body, and the second ends of the adsorbers successively communicate to a light product port, to light reflux exit ports and to light reflux return ports provided in a second valve surface between the adsorber housing body and the second valve body; the process including for each of the adsorbers in turn:

(a) supplying feed gas mixture at a feed pressure through the feed port to the adsorber over a feed interval which is substantially 1/3 of the cycle period so as to pressurize the adsorber to substantially the higher pressure, and then to deliver light product gas from the light product port at substantially the higher pressure less flow frictional pressure drops,

(b) withdrawing light reflux gas enriched in the less readily adsorbed component from the light reflux exit ports, in part to depressurize that adsorber after the feed interval,

(c) withdrawing second product gas at an exhaust pressure through the exhaust port from the adsorber over an exhaust interval which is substantially 1/3 of the cycle period so as to depressurize that adsorber to substantially the lower pressure while delivering the second product gas,

(d) returning light reflux gas enriched in the less readily adsorbed component from the light reflux return ports so as to purge the adsorber in the latter part of the exhaust interval and then to partially repressurize the adsorber prior to the next feed interval,

so that feed gas is continuously supplied to substantially one adsorber at time, and exhaust gas is continuously removed from substantially one adsorber at a time.

33. Apparatus for pressure swing adsorption separation of a gas mixture containing a more readily adsorbed component and a less readily adsorbed component, with the more readily adsorbed component being preferentially adsorbed from the gas mixture by an adsorbent material under increase of pressure between a lower pressure and a higher pressure, so as to separate from the gas mixture a heavy product gas enriched in the more readily adsorbed component and a light product
adsorber housing body cooperating with first and second valve bodies mutually defining an axis of relative rotation between the adsorber housing body and the

first and second valve bodies, and with drive means to establish relative rotation between the adsorber housing body and the first and second valve bodies at a rotational period which defines a pressure swing adsorption cycle period, the adsorber housing body containing a cooperating set of three adsorbers equally angularly spaced about the rotational axis, each adsorber having a flow path contacting the adsorbent material between first and second ends of the adsorber, the first ends of the adsorbers communicating by first apertures to a first valve surface between the first valve body and the adsorber housing body, and the second ends of the adsorbers communicating by second apertures to a second valve surface between the adsorber housing body and the second valve body; the first valve surface having feed and exhaust ports engaging successively in fluid communication with the first apertures, and the first valve surface having a light product port, and first, second and third light reflux exit ports and first second and third light reflux return ports engaging successively in fluid communication with the second apertures; the apparatus further including feed supply means communicating by fluid transfer means to the feed port in the first valve body and second product exhaust means communicating by fluid transfer means to the exhaust port; the first and third light reflux exit ports communicating directly to the first and third light reflux return ports respectively within the second valve body, and the second light reflux exit port communicating to a buffer chamber communicating in turn to the second light reflux return port within the second valve body, and with fluid transfer means for delivering the light product from the second valve body; and the angular positions and widths of the ports and apertures being configured so that for each adsorber in sequence the following steps are performed:

(a) the first aperture of the adsorber is opened to the feed port through which feed gas mixture is supplied by the feed supply means over a feed interval of substantially 1/3 of the cycle period so as to pressurize the adsorber to substantially the higher pressure, while the second aperture of the adsorber is then opened to the light product port in the feed interval so as to deliver light product gas at substantially the higher pressure less flow frictional pressure drops,

(b) the second aperture of the adsorber is opened sequentially to the first, second and third light reflux exit ports so as to deliver light reflux gas enriched in the less readily adsorbed component and to depressurize the adsorber after the feed interval,

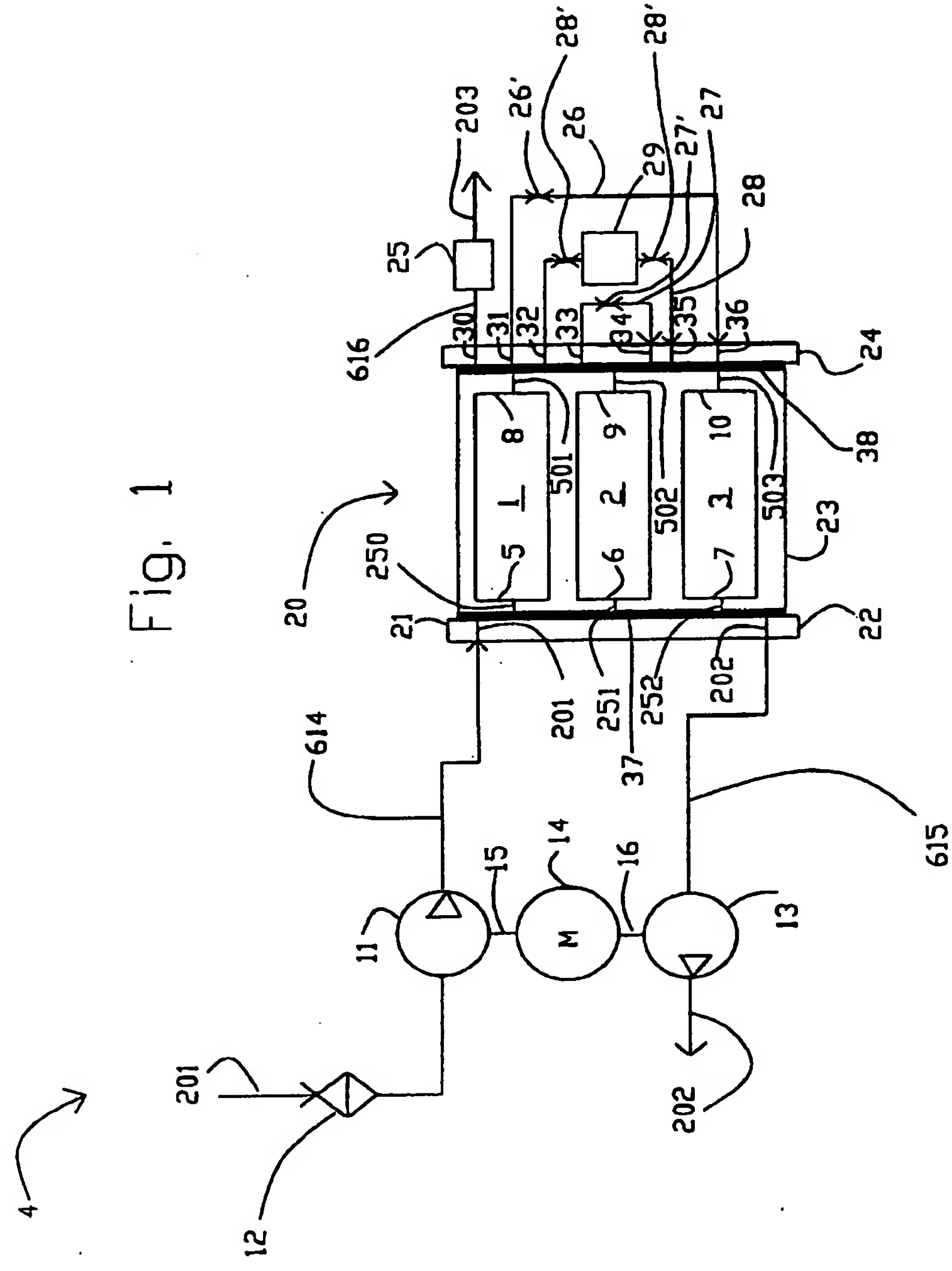
(c) the first aperture of the adsorber is opened to the exhaust port through which second product gas is exhausted by the second product exhaust means at an exhaust pressure over an exhaust interval which is substantially 1/3 of the cycle period so as to depressurize that adsorber to substantially the lower pressure and to deliver the second product gas,

(d) the second aperture of the adsorber is opened sequentially to the third, second and first light reflux return ports so as to purge the adsorber in the latter part of the exhaust interval and then to partially repressurize the adsorber prior to the next feed interval.

34. The apparatus of claim 33, in which the first and second valve bodies are stationary, and the relative motion is established by rotation of the adsorber housing body as a rotor.

35. The apparatus of claim 33, in which the adsorber housing body is stationary, and the relative motion is established by rotation of the first and second valve bodies.

Fig. 1


4
12
201
202
11
14
13
15
16
614
615
616
20
21
22
23
24
25
26
26'
27
27'
28
28'
29
30
31
32
33
34
35
36
37
38
201
202
203
250
251
252
501
502
503
5
6
7
8
9
10
1
2
3
M

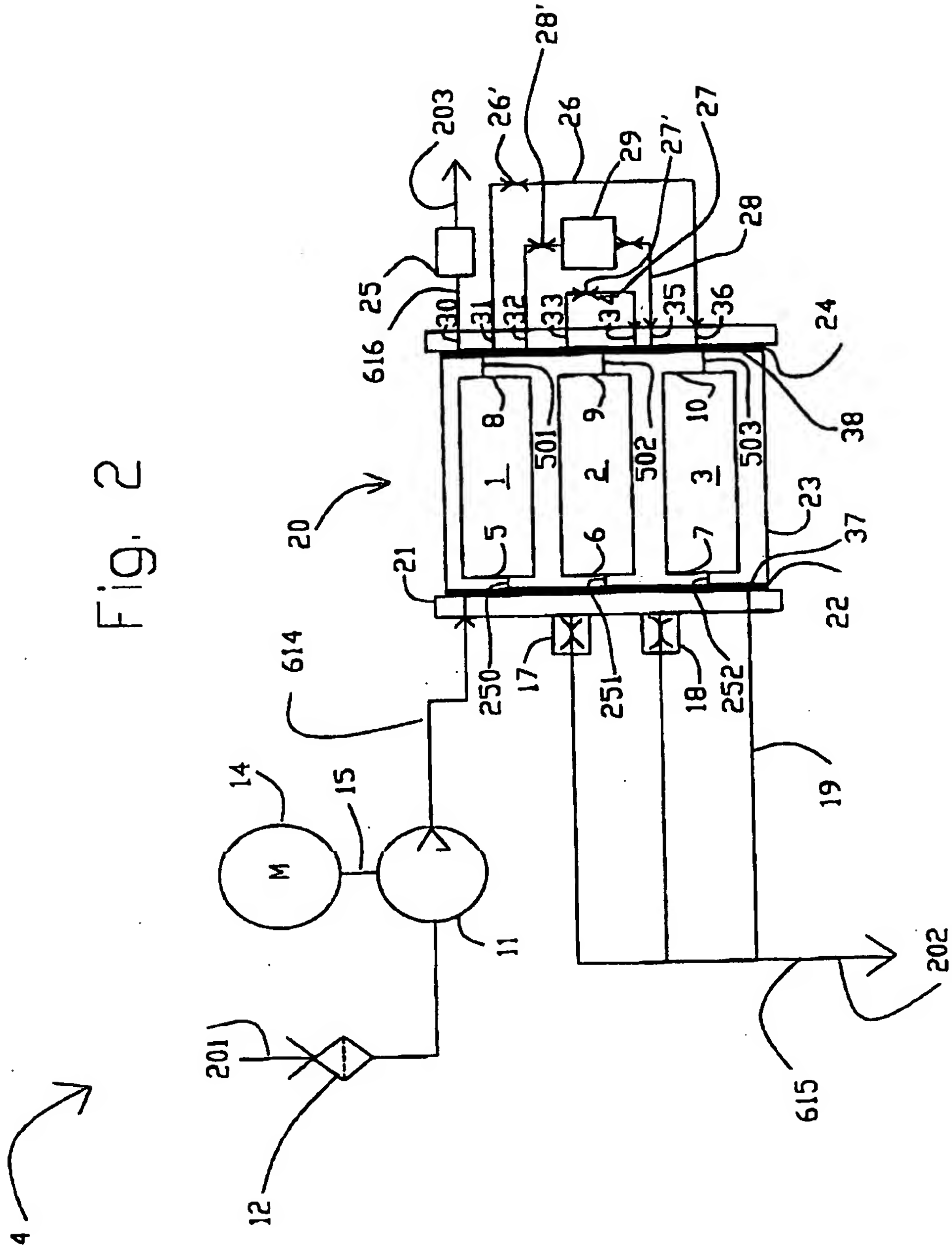

4
12
201
11
M
14
15
614
250
17
251
18
252
19
615
202
20
21
22
23
37
5
6
7
1
2
3
8
9
10
501
502
503
38
24
616
25
30
31
32
33
34
35
36
203
26'
28'
26
29
27'
27
28

Fig. 2

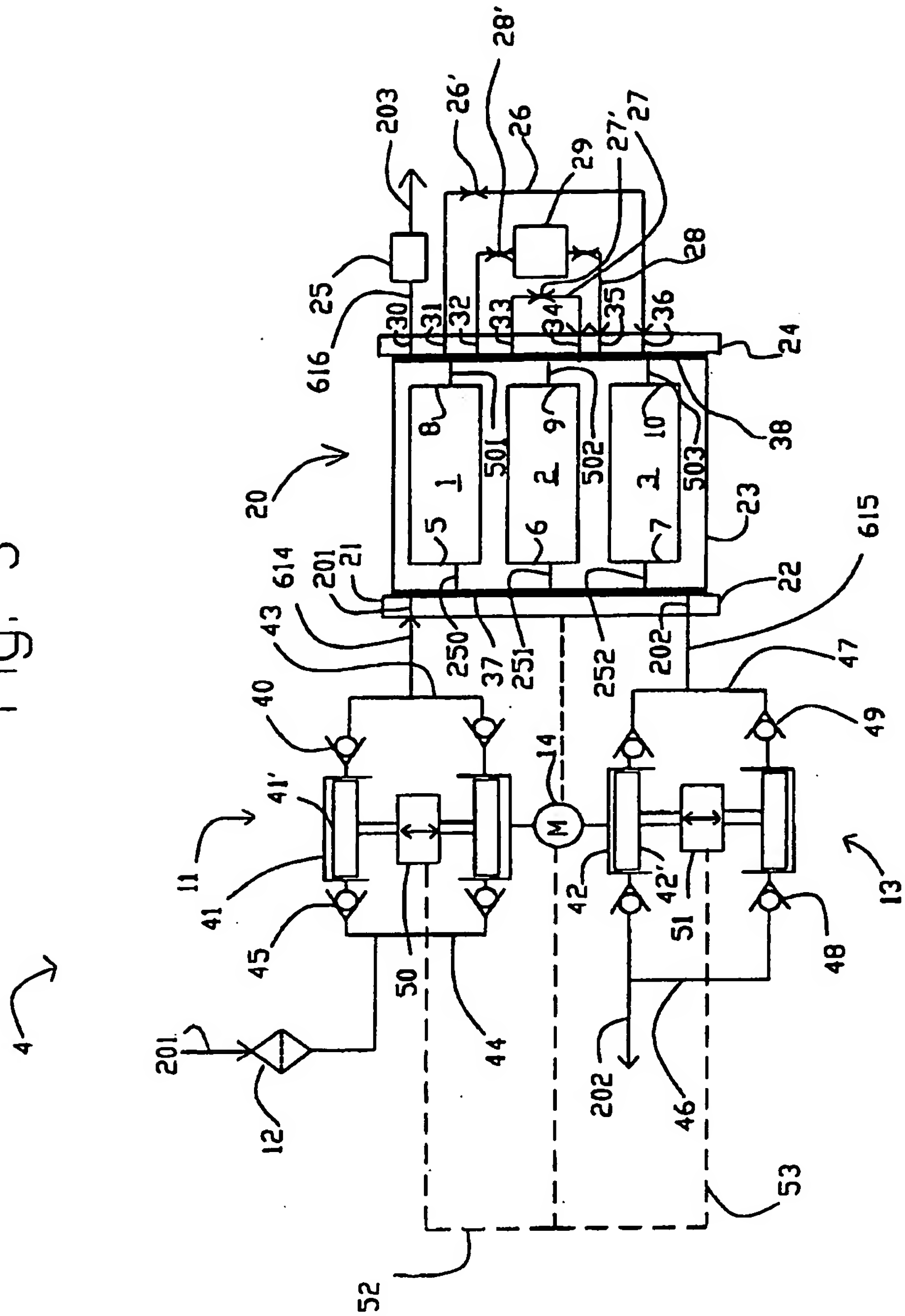


Fig. 3

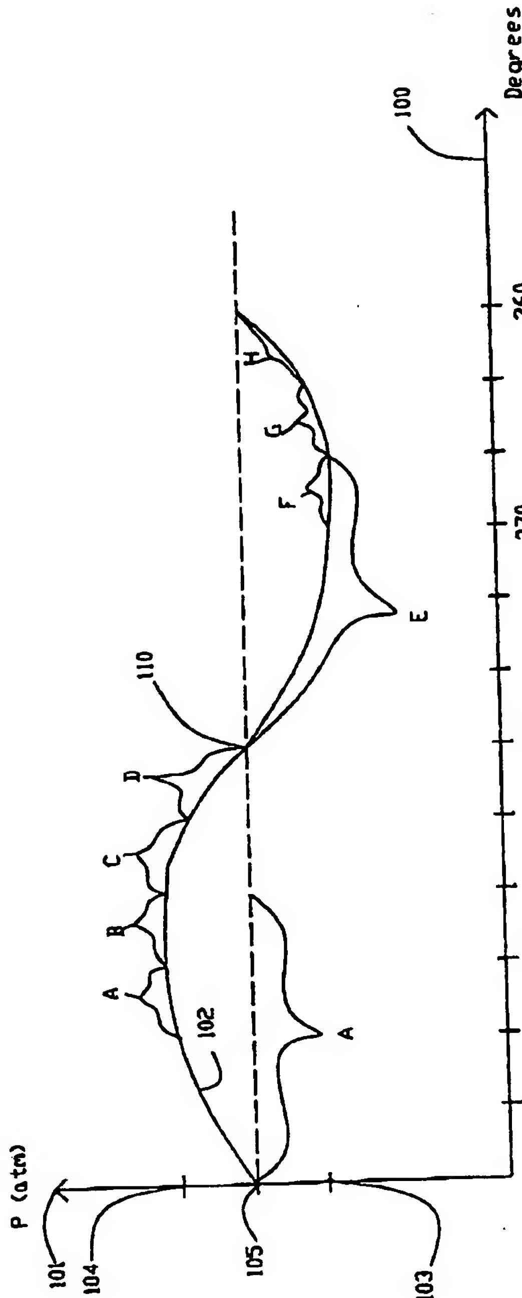

Degrees
100
360
270
180
90
P (atm)
101
104
105
103
102
110
A
B
C
D
E
F
G
H
A

Fig. 4

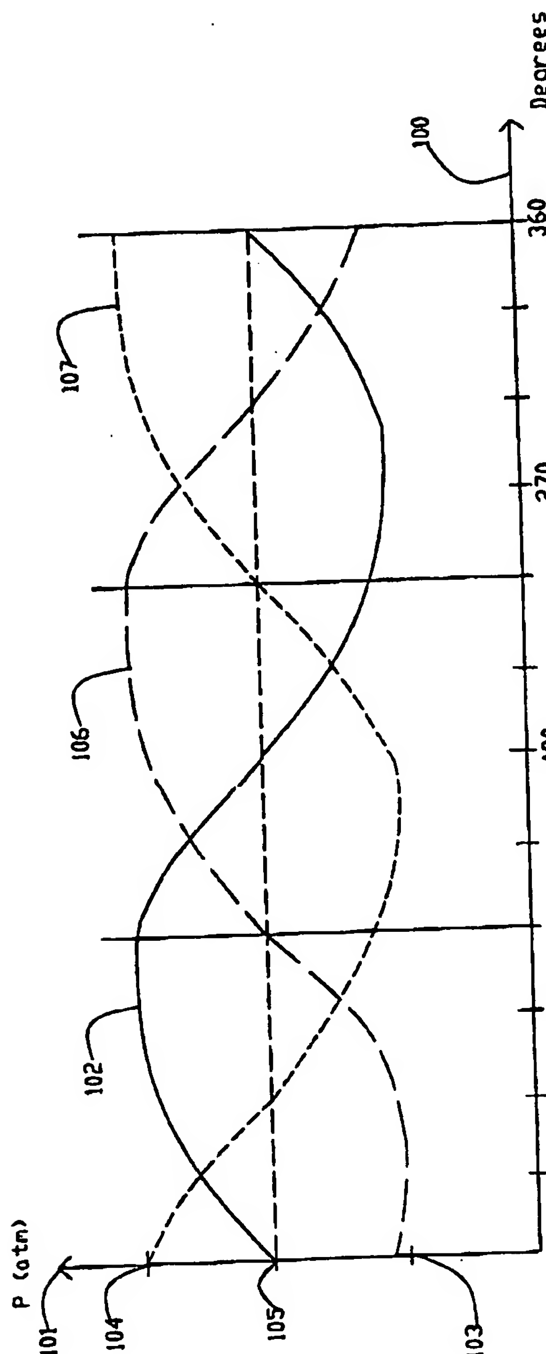


Fig. 5

Fig. 6

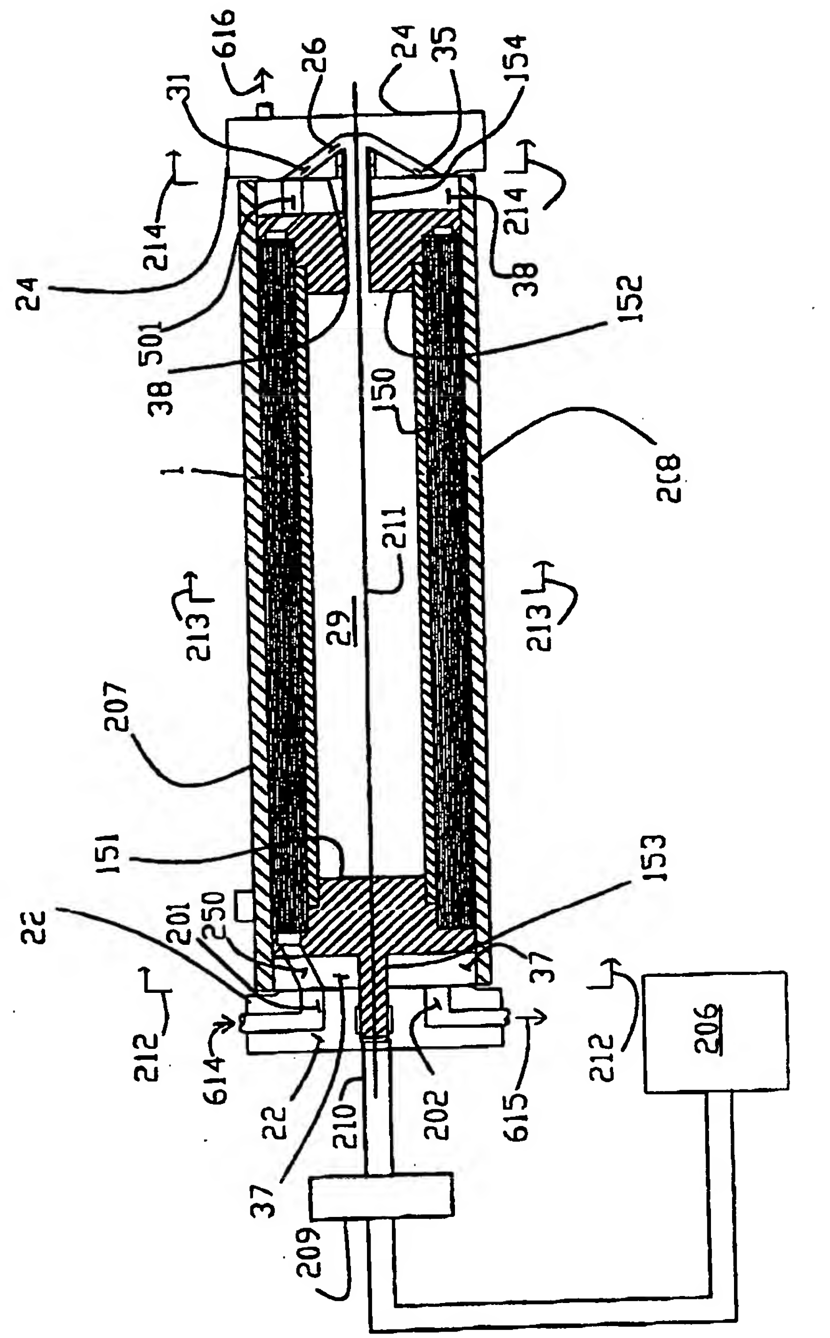

616
31
26
24
35
154
214
214
24
501
38
38
152
150
1
218
211
29
213
213
207
151
153
22
201
250
37
212
614
22
37
210
202
615
212
206
209

Fig. 7a

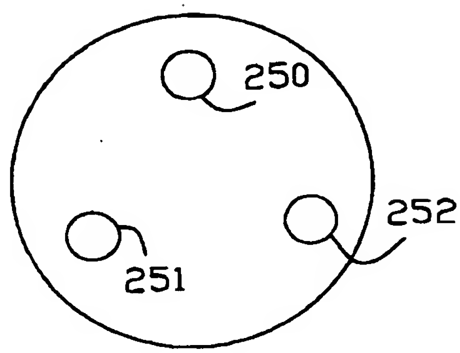


Fig. 7b

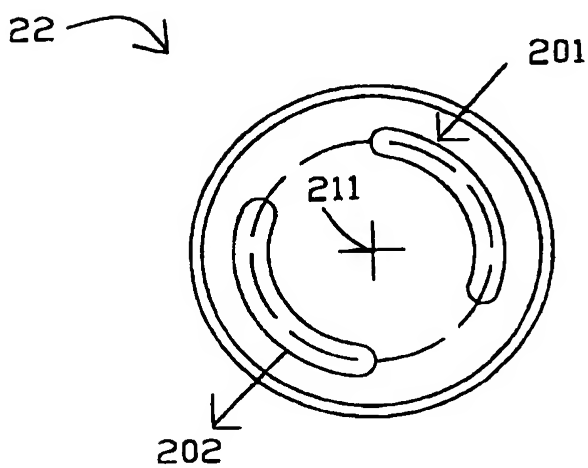


Fig. 8a

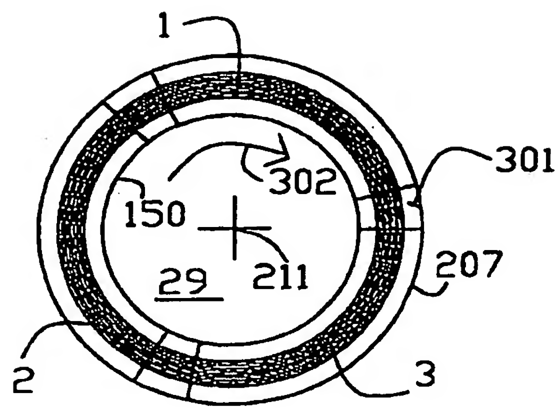


Fig. 8b

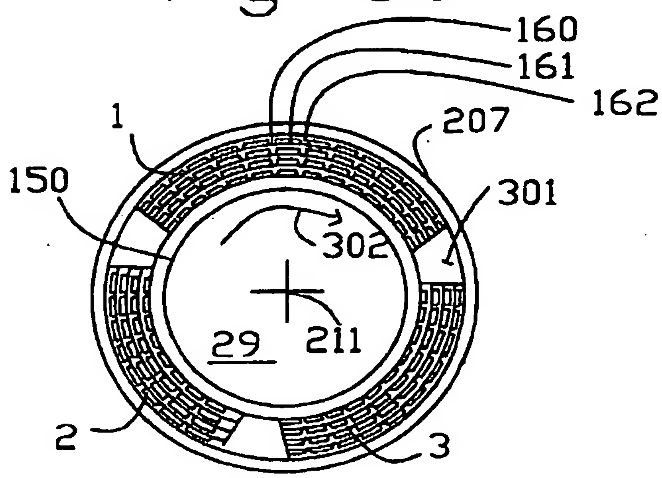


Fig. 9

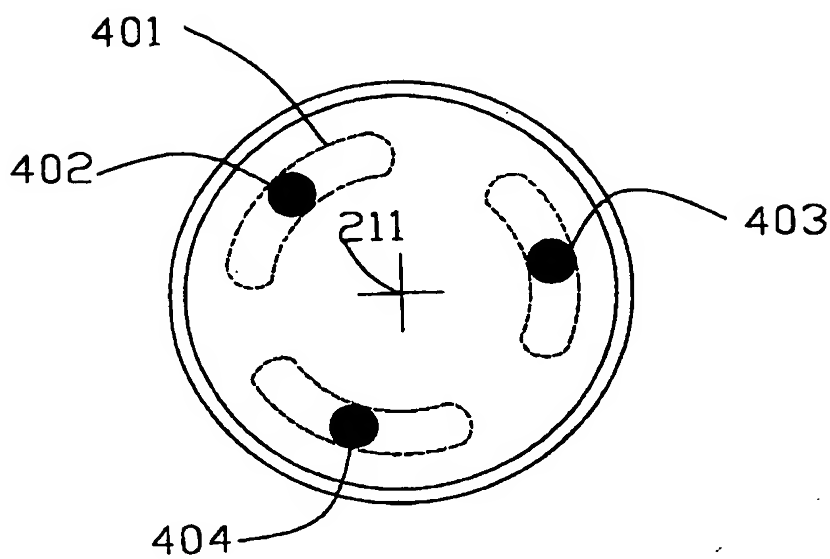


Fig. 10a

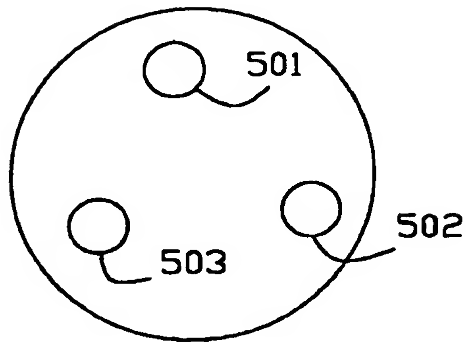
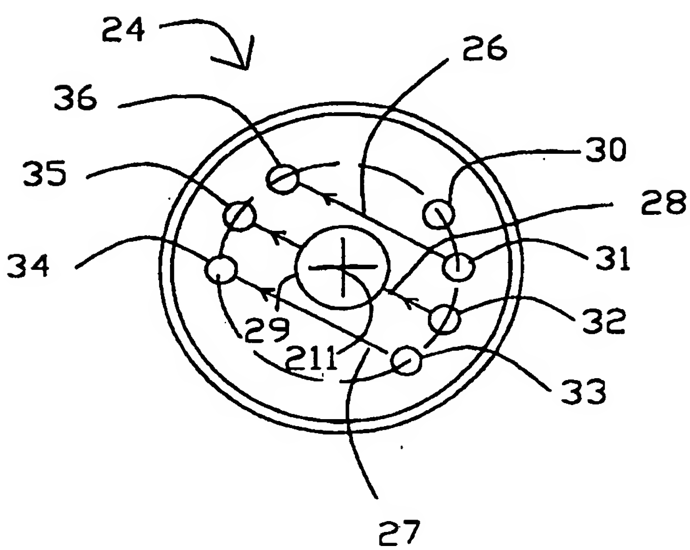


Fig. 10b



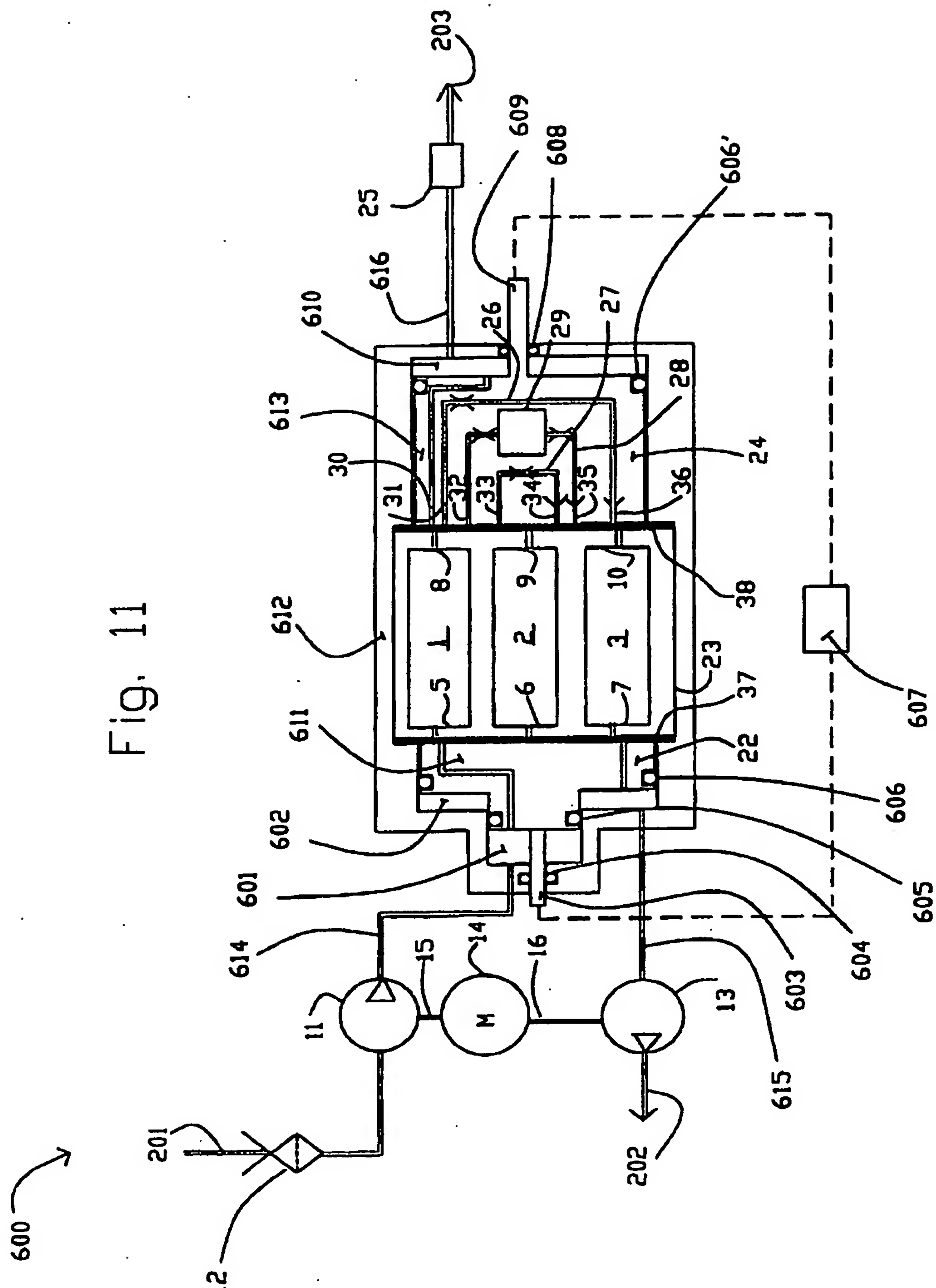

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Fig. 11